When the Space Shuttle Finally Flies

By RICK GORE

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THE SECOND SPACE AGE is about to begin. Space shuttle flight one will depart Cape Canaveral for low earth orbit as early as March 14. Its trip will be short—two and a third days. Astronauts John Young and Bob Crippen will take their flagship *Columbia* around the world 36 times to test its wings. Then a steep descent down onto the Mojave Desert. But at least three dozen space flights will follow, for tours of a week or more. *Columbia* will be joined by *Challenger*, *Discovery*, and *Atlantis*. By the late 1980s this fleet of orbiters could be making about 50 flights a year.

What is the space shuttle? Most people know that it sometimes rides piggyback on a Boeing 747. Many have heard about its main engines bursting into flame on the test stand, some of its protective tiles falling off, and the other expensive problems that have delayed *Columbia*'s maiden flight for more than two years. Yet ask someone how the shuttle is going to get to space, or better still what our nine-billion-dollar super machine will do up there, and the answer will likely be a stammer or a shrug. The space shuttle has come of age with an identity crisis.

Basically, the shuttle is a spacefaring cargo ship that can be used over and over again. Not only will it take satellites, military hardware, and people to space, but it will also bring them back. It will replace all other American satellite launching vehicles. If, once in orbit, a satellite fails, the shuttle can retrieve it for servicing. The shuttle will ferry telescopes, earth-scanning cameras, laboratories, and eventually construction equipment into orbit. It will move industry into space. Apollo's moon-landing program, Skylab, and the missions to the planets were the age of space exploration. The shuttle begins the age of space exploitation.

At times the shuttle also seems to be the beginning of the people's space program. "I'm convinced that by 1990 people will be going on the shuttle routinely—as on an airplane," says Robert Freitag, an advanced programs planner at the National Aeronautics and Space Administration.

For the first time women and minorities will be in the astronaut corps. My daughter could well grow up to help build a solar-power space structure as big as Manhattan Island that would convert solar energy to

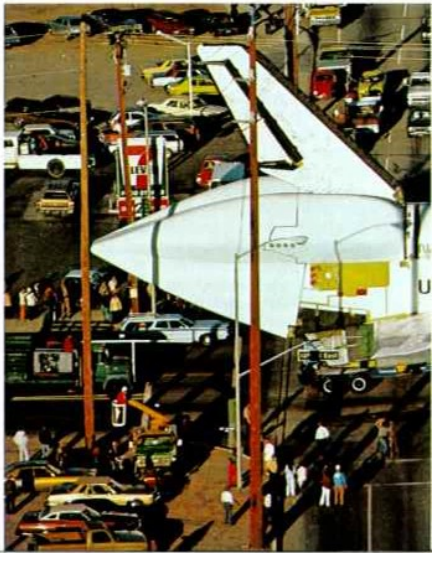
Spaceborne at last? *After a two-year delay, the space shuttle is poised for launch this spring from Cape Canaveral. The reusable shuttle offers multiple options for the unique environment of space: astronomy, communications, biomedicine, defense, even manufacturing. The payload vehicle, the earth orbiter that looks like an aircraft mated to rockets and fuel tank* ***(left)****, can ferry satellites and instruments to orbit and return to service them.*

Workhorse in space

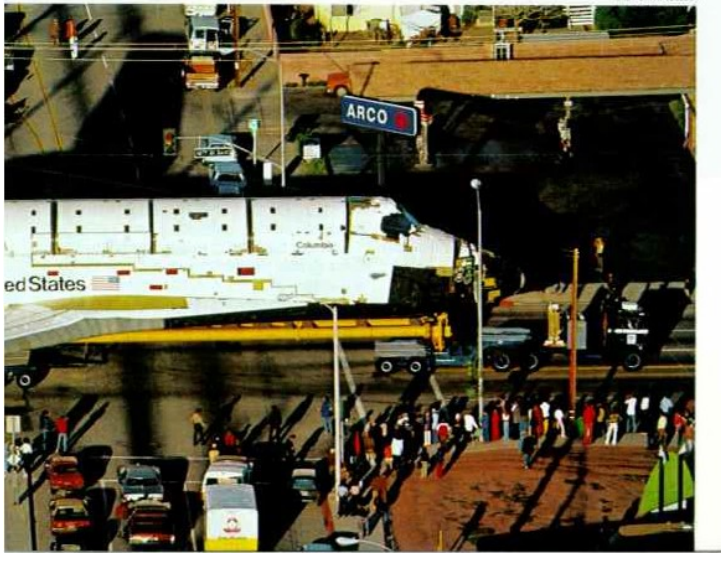
*JAMMING terrestrial traffic, the orbiter "Columbia" creeps through Lancaster, California (**right**), after assembly in Palmdale. At NASA's Dryden Flight Research Center near Edwards, the orbiter was fastened atop a Boeing 747 for a journey to Cape Canaveral (**above**).*

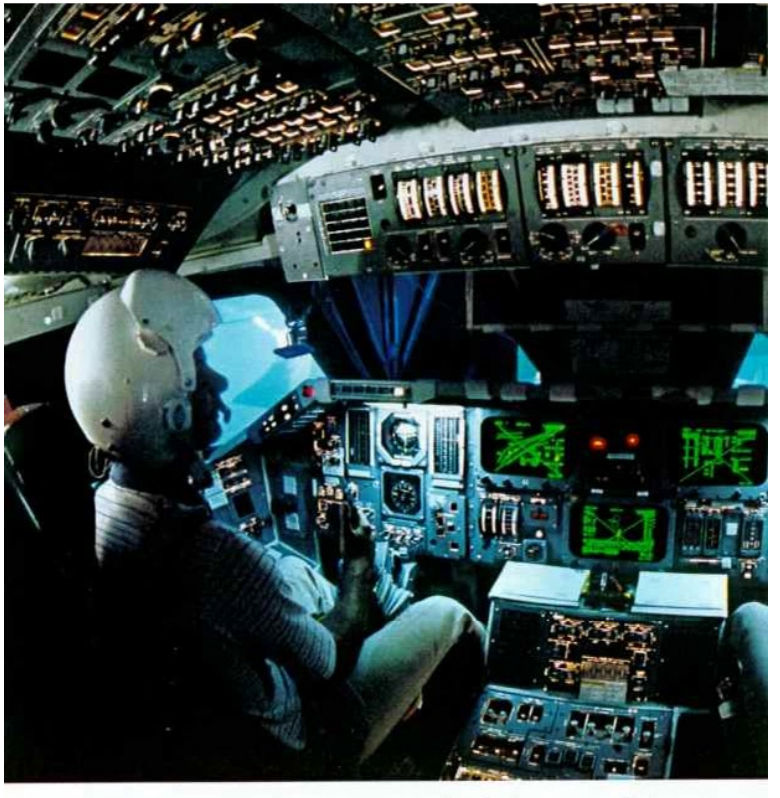
In the giant building at left the "Columbia" was joined to its booster rockets and external tank. It will lift off from Launch Complex 39A, center, where Apollo astronauts began their journeys to the moon.

The many-faceted "Columbia" will launch like a missile, orbit like a spacecraft, and return to earth like an aircraft. Its wings will function from atmospheric reentry to landing—about thirty minutes.



KERBY SMITH (BELOW)





microwave energy and beam it to earth.

Already an unexpectedly high number of student and civic groups, corporations, private individuals, and foreign countries have bought "getaway specials" from NASA. These are canisters in which anyone anywhere can send experiments and inventions into space for as little as $3,000.

Even Hollywood is enthused. Director Steven Spielberg holds a getaway-special reservation but has no idea as yet what to do with it. *The China Syndrome* screenwriter, Mike Gray, told me that "the space shuttle is the set of the future." Still others see the shuttle as the first step toward colonies in space and human emigration from earth.

More immediately, astronauts riding the space shuttle will be deploying and servicing elaborate switching stations for telephones and television. Before the end of the century we should be able to make an inexpensive telephone call from a wristwatch telephone via satellite anywhere in the world. Less certain but potentially just as profitable is the prospect of building, with the shuttle's help, floating factories that take advantage of the unique ultralow gravity of space.

Finally, the shuttle will be a military machine. The Air Force has reserved 13 of its first 44 flights. A new surveillance system will go up. Our next war could be fought between satellites that hunt and destroy each other or even knock out missiles with lasers or high-energy death beams.

For a while the space shuttle will make only test flights. Not until 1982 will it fly its first regular mission, deploying a giant tracking and data-relay satellite. That gives us time to get to know this complex machine.

The shuttle that will spew fireballs and steam across the launchpad at Kennedy Space Center at Cape Canaveral has three main components: an orbiter, external tank, and two solid-rocket boosters, all bolted together. This ungainly configuration will stand 184 feet tall—about half the height of the Apollo lunar launch assembly.

***Automated flight** results from four computers that brief pilots by means of TV screens at center. Though pilots can take over in emergencies, an orbiter's flight is usually monitored by the two-man crew and a ground team of four. Scores of ground controllers monitored moon vehicles.*

The orbiter, which looks like a small, fat airliner, is the core of the system. It is what goes back and forth between earth and space. The orbiter features work and living quarters for as many as seven people and a 60-foot-long payload bay for stowing cargo. This bay could carry to space the weight equivalent of five adult African elephants.

However, the most obvious component of the shuttle will be the mammoth white bullet-shaped external tank. The external tank carries the enormous volume of liquid hydrogen and oxygen burned by the orbiter's main engines. In just eight minutes these three ultrahigh-performance engines will consume enough propellant to fill 18 backyard swimming pools.

If the orbiter itself had to carry all that liquid, it would be far too big. So instead the orbiter will ride on its fuel tank, and then, just before reaching orbit, it will drop the empty tank into the Indian Ocean.

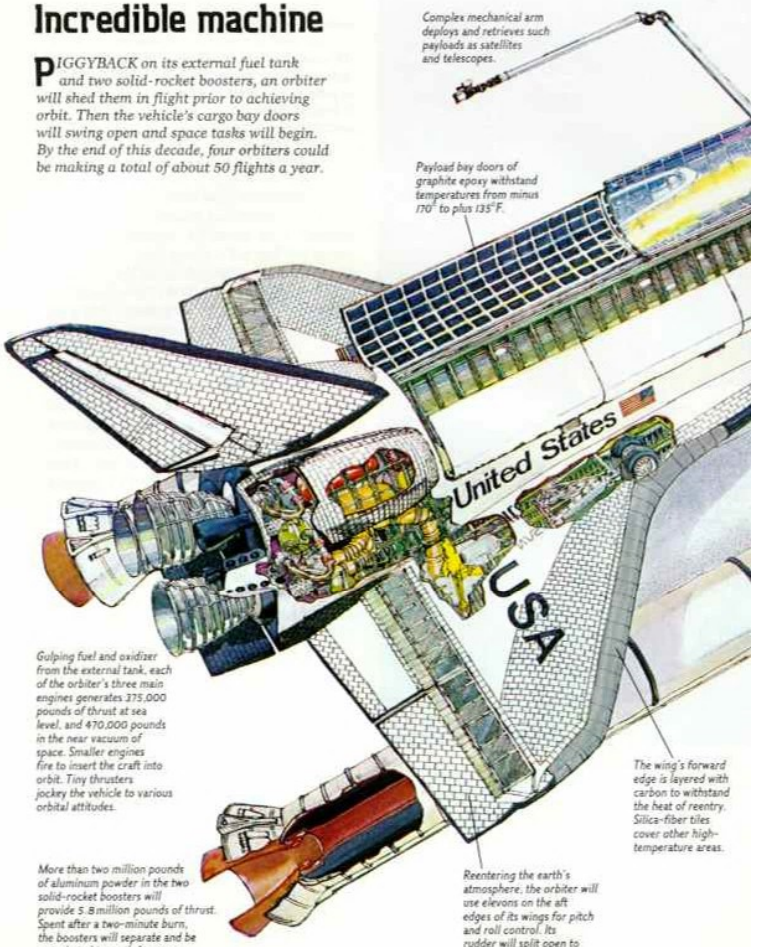
Riding Captive Flame Into Space

Unfortunately, on the ground the fuel in that tank weighs a million and a half pounds. As powerful as they are, the orbiter's main engines could scarcely budge this load. So a third component is needed, the solid-rocket boosters. Solid rockets, which burn a highly explosive aluminum powder, have long been used by the military. They have tremendous get-up-and-go. One I saw being test-fired in Utah looked as if it were spitting the sun out its tail as it sent a blinding holocaust across the desert.

No man has ridden solid rockets before, largely because they are hard to control. Once ignited, they are on for good. No second thoughts. *(Continued on page 327)*

Incredible machine

PIGGYBACK on its external fuel tank and two solid-rocket boosters, an orbiter will shed them in flight prior to achieving orbit. Then the vehicle's cargo bay doors will swing open and space tasks will begin. By the end of this decade, four orbiters could be making a total of about 50 flights a year.



Complex mechanical arm deploys and retrieves such payloads as satellites and telescopes.

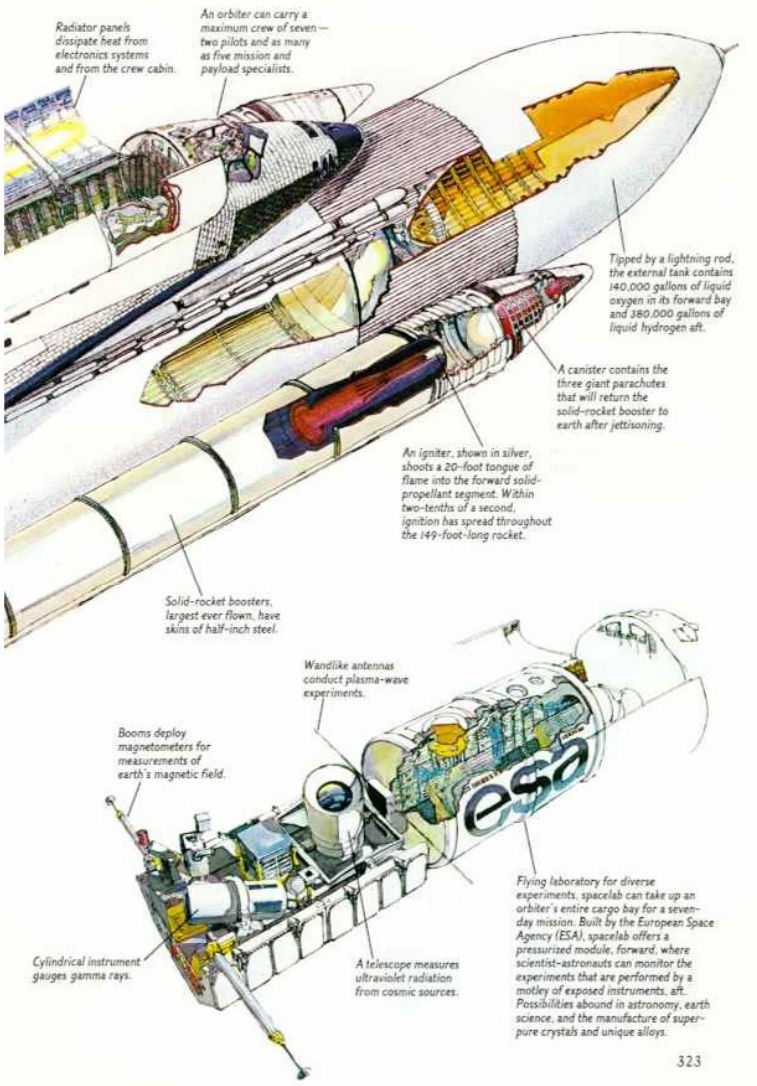
Payload bay doors of graphite epoxy withstand temperatures from minus 170° to plus 135°F.

Gulping fuel and oxidizer from the external tank, each of the orbiter's three main engines generates 375,000 pounds of thrust at sea level, and 470,000 pounds in the near vacuum of space. Smaller engines fire to insert the craft into orbit. Tiny thrusters jockey the vehicle to various orbital attitudes.

More than two million pounds of aluminum powder in the two solid-rocket boosters will provide 5.8 million pounds of thrust. Spent after a two-minute burn, the boosters will separate and be parachuted to earth for reuse.

Reentering the earth's atmosphere, the orbiter will use elevons on the aft edges of its wings for pitch and roll control. Its rudder will split open to function as a speed brake.

The wing's forward edge is layered with carbon to withstand the heat of reentry. Silica-fiber tiles cover other high-temperature areas.



Radiator panels dissipate heat from electronics systems and from the crew cabin.

An orbiter can carry a maximum crew of seven—two pilots and as many as five mission and payload specialists.

Tipped by a lightning rod, the external tank contains 140,000 gallons of liquid oxygen in its forward bay and 380,000 gallons of liquid hydrogen aft.

A canister contains the three giant parachutes that will return the solid-rocket booster to earth after jettisoning.

An igniter, shown in silver, shoots a 20-foot tongue of flame into the forward solid-propellant segment. Within two-tenths of a second, ignition has spread throughout the 149-foot-long rocket.

Solid-rocket boosters, largest ever flown, have skins of half-inch steel.

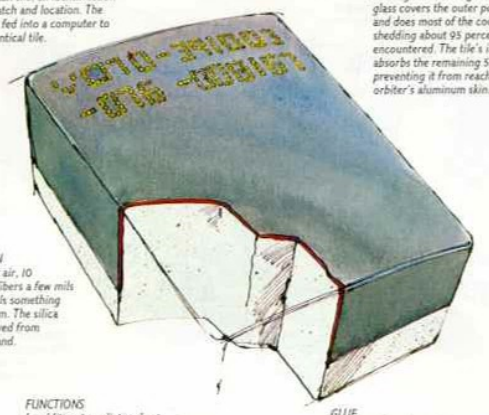
Wandlike antennas conduct plasma-wave experiments.

Booms deploy magnetometers for measurements of earth's magnetic field.

Cylindrical instrument gauges gamma rays.

A telescope measures ultraviolet radiation from cosmic sources.

Flying laboratory for diverse experiments, spacelab can take up an orbiter's entire cargo bay for a seven-day mission. Built by the European Space Agency (ESA), spacelab offers a pressurized module, forward, where scientist-astronauts can monitor the experiments that are performed by a motley of exposed instruments, aft. Possibilities abound in astronomy, earth science, and the manufacture of super-pure crystals and unique alloys.



IDENTIFICATION
Different for each tile, an identification number tells batch and location. The number can be fed into a computer to produce an identical tile.

COATING
Black-glazed coating of borosilicate glass covers the outer portion of a tile and does most of the cooling job, shedding about 95 percent of the heat encountered. The tile's interior absorbs the remaining 5 percent, preventing it from reaching the orbiter's aluminum skin.

COMPOSITION
Ninety percent air, 10 percent silica fibers a few mils thick, a tile feels something like plastic foam. The silica fibers are derived from high-quality sand.

FUNCTIONS
In addition to radiating heat, tiles establish the aerodynamic shape of the orbiter. During launch they will undergo severe acoustic vibration, many times greater than a thunderclap.

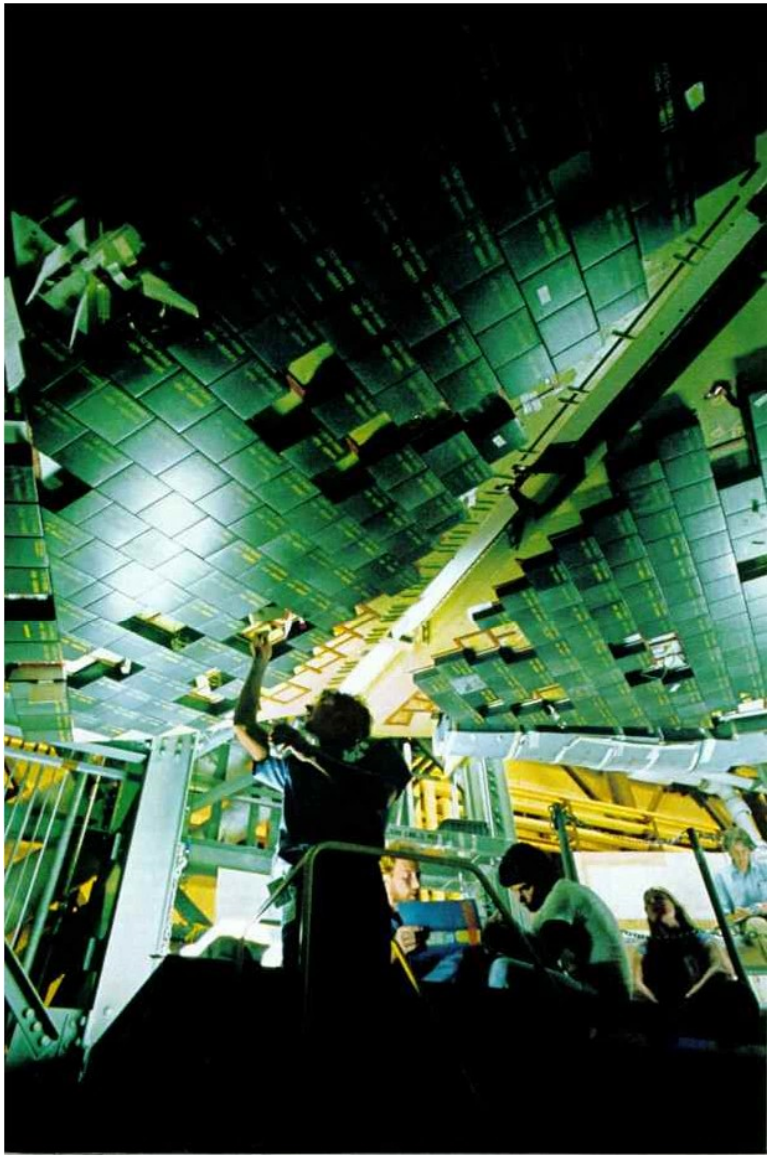
GLUE
Silicon-rubber glue, similar to common bathtub caulking, bonds a tile to a felt pad, not shown, that is in turn bonded to the orbiter's skin. The felt absorbs the stresses of airframe bending that could damage the rigid, brittle tiles.

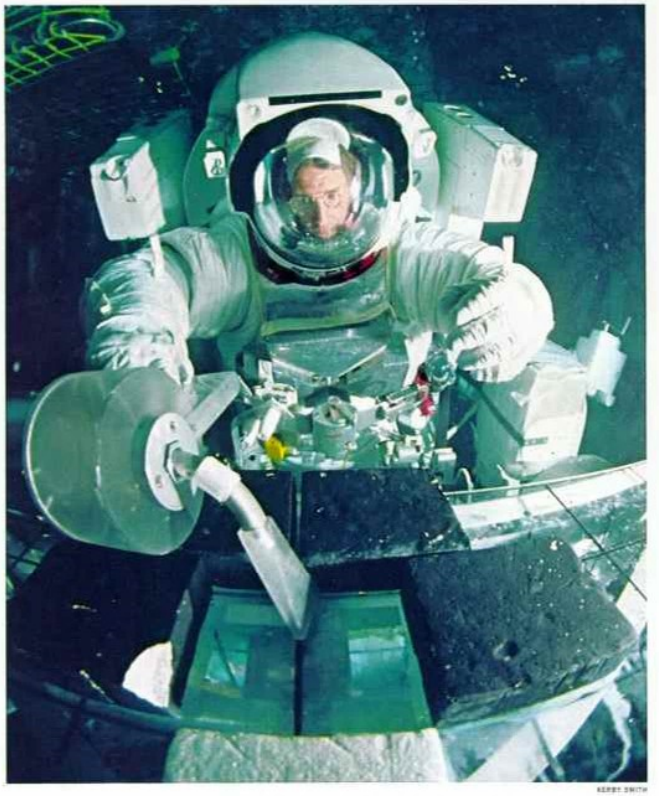
Those incredible, troublesome tiles

*LIKE AN UNFINISHED jigsaw puzzle, heat-dissipating tiles line the underside of "Columbia" (**right**). Without them, the orbiter would burn up on reentering the earth's atmosphere. Approximately 34,000 tiles cover about 70 percent of the orbiter's surface.*

*At a Lockheed Missiles and Space Company facility in Sunnyvale, California (**left**), a technician exhibits surgeonlike concentration as he masks a tile before a ceramic coating is applied. The coating enables the tiles to withstand temperatures up to 2300°F.*

Computer-controlled machines cut the tiles; no two are exactly alike. Installation and testing difficulties made them one of the major elements in the shuttle program's delay.



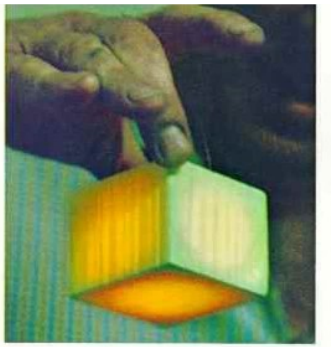


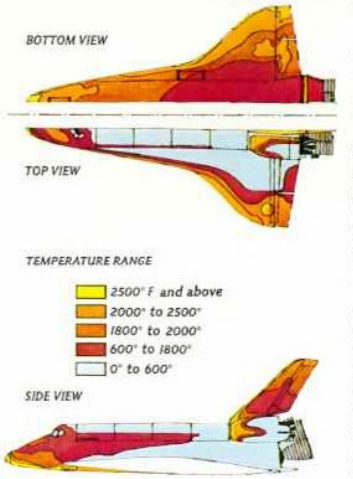
KERBY SMITH

Tile troubleshooting class *convenes underwater for astronaut Richard H. Truly* (**above**) *at NASA's Johnson Space Center in Houston. Problem: Fill the void left by a lost tile. Danger: In space the loss of tiles shielding critical areas, such as hydraulic lines, could threaten the orbiter itself.*

Experiencing reduced gravity, Truly uses a king-size caulking gun to fill a tile space with glue that contains an ablating substance. The patch would flake off gradually during reentry, thus shielding the orbiter.

Zones of equal temperature, shown as a thermogram (**right**)*, dictate the type of protective material needed.*





Relatively cool cargo bay doors are covered with fireproof felt. Tiles take over the middle range up to 2300°F. Heated in a kiln beyond this temperature, a cube releases interior heat so slowly that it can be held at the corners (**top**)*. Reinforced carbon protects the nose and wing edges where temperatures higher than 2500°F are expected.*

(Continued from page 321) No throttle back. That has been fine for launching warheads, but not for the subtleties of manned space flight.

On the shuttle the solid rockets are there just for the muscle. Two are bolted onto the external tank, and for two minutes they provide 5.3 million pounds of thrust. That is about what it would take to get 25 fully loaded 747s airborne. Once the solid fuel is exhausted, explosives fire the rockets away, to be recovered by a ship off Florida for reuse.

Finding the Orbital Flyway

So that is the system. One orbiter, one external tank, and two solid-rocket boosters, all taking off at the same moment. Two minutes after launch the solid rockets drop off. A few moments before reaching orbit, the orbiter sheds the external tank. Then it fires up two secondary engines, called the orbital maneuvering system (OMS), which put it in revolution around the earth.

During its orbital flight and later descent, these OMS engines and 44 smaller thrusters placed strategically along the spacecraft enable the orbiter to turn over or to straighten up, to change orbits or to rendezvous and dock. They also make the precise adjustments needed to take the orbiter out of orbit, to bank and swerve it safely through the intense heat of reentry.

In April of 1978, when I first saw the orbiter *Columbia* taking shape, there was still hope that it would fly the next year. In its huge hangar at the Rockwell Corporation Facility in Palmdale, California, the *Columbia* looked much like any large aircraft under construction. Its green-coated shell sat amid scaffolding, with men by the score crawling around the sides and in and out of cavities in the fuselage. Men welding. Men wiring and inspecting. Men scratching and often shaking their heads.

All these wires would later be hidden, but at this stage the *Columbia* was like a body with its skin off and its nerve ends showing. This nervous system is one of the hallmarks of the orbiter.

Nothing as big as the *Columbia* has ever been put into orbit, and nothing with wings has ever flown anywhere near the 17,500 miles an hour the orbiter must encounter. It is, nevertheless, the orbiter's brains as much

as its brawn that make it the most ambitious flying machine ever built.

From nine minutes before lift-off until just before touchdown, the shuttle flight will be almost totally automated. During critical phases of flight the orbiter's computers will perform some 325,000 operations a second. These computers are ten times faster than those controlling the Apollo spacecraft, with six times the memory.

The shuttle's computer system is called "quad-redundant." Astronaut Deke Slayton explained: "There are four computers, with a fifth as a backup. The four main computers all process the same information. All have to agree. If one disagrees with the other three, it is turned off. If one of the remaining three changes its mind, the majority wins again. If the last two can't agree, the backup computer is turned on. It decides. It can't be wrong."

This redundancy eliminates the need for the scores of mission controllers who kept tab on all the Apollo spacecraft systems and made crucial decisions for the astronauts.

"With the shuttle we are talking about four ground controllers manning a flight versus hundreds on a full-blown Apollo mission," said flight controller Pete Frank at the Johnson Space Center in Houston.

Instead of ground control, shuttle astronauts will rely largely on three television displays in the cockpit (pages 320-21). Two TV screens provide data on trajectory and guidance control. The third handles the orbiter's electrical, environmental, hydraulic, and many other systems.

If something goes wrong—say a heater in a hydrogen tank malfunctions and the pressure of the liquid hydrogen fuel subsequently drops—astronauts will hear a warning tone in their headsets and see a master alarm light flash on. A control-panel light indicating hydrogen pressure also turns on. The astronauts can then use a computer keyboard to call up details of the problem.

"It's a convenience," says astronaut Vance Brand. "This vehicle is so complicated. There's far too much data to monitor continuously. This system frees us in orbit for work on our most immediate tasks."

"Office" With an Awesome View

Except for the three TV screens and some 1,400 switches and circuit breakers, the orbiter cockpit looks much like that of any transport plane. Directly behind the cockpit, though, is a small area with still more control boards and a spectacular view out over the long unpressurized cargo bay. Here work the mission specialists, the people who actually carry out the business of a particular flight. They will be able to watch as they raise the orbiter's big remote manipulator arm, pick up a satellite stored in the bay, and plunk it overboard.

(The astronaut corps will be broken into two groups. Pilots fly the machine up and back. Mission specialists run the show once in orbit. Later, a third category, the payload specialists, will be added. These will be outside experts: A solar physicist, for instance, may be brought along on a solar astronomy mission.)

The orbiter cabin has two levels. Neither is spacious. Climbing onto the flight deck and into a cockpit seat was a feat of contortion. However, my way was impeded by bulky pilot-ejection seats that will be removed after the shuttle demonstrates several times that it can launch safely.

Beneath the flight deck are the Spartan living quarters, which include three seats, a galley, a washroom, space for either upright sleeping hammocks or berths, stowage, and an airlock exit into the payload bay. About ten people could stand shoulder to shoulder in these living quarters. The decor could be called modern metal file cabinet. As the *Columbia*'s first commander, John Young, put it, "A seven-day mission with six people is going to be pretty austere."

The interior of the orbiter may not represent a breakthrough in comfort, but its exterior has certainly pushed technology. One overriding problem in designing a shuttle was how to keep the spacecraft from burning like a meteorite when it reenters the atmosphere. Parts of the orbiter will register temperatures higher than 2500°F.

Earlier spacecraft had chemical heat shields that absorbed the heat, charred, and flaked off. But a shuttle orbiter may have to reenter the atmosphere 100 times or more. It must have a reusable heat shield.

The solution was to cover much of the orbiter's aluminum skin with tiles made from fibers of 99.7 percent pure silica glass. When they are that pure, silica fibers conduct virtually no heat.

The Stuff to Keep Things Cool

Engineer Ed Law pulled a small glowing cube of this white, plastic-foamlike material from a 2500°F kiln at the Lockheed Missiles and Space Company's Sunnyvale, California, plant. It had taken more than 30 minutes for the furnace to heat the cube cherry hot. Law picked the cube up by its corners and handed it to me.

"Be careful to touch only the points of the corners," he said. "A Japanese newsman nearly lost his fingerprints doing this."

When I took the cube, just a mild warmth radiated into my palms. Three minutes later the cube's 1700° interior still glowed. Yet I could touch the cube anywhere on its surface. The heat very near the surface had escaped into the air. That trapped within would take hours to work its way out through the ultrapure silica fibers.

Conversely, the brief intense heat generated by reentry will not be able to get through the orbiter's tiles: 90 percent of it will be reradiated into the atmosphere.

Some 34,000 of these tiles, coated with a

MICHAEL LAMTON AND JON SCHNEEBERGER

Radiating confidence, *"Columbia's" commander John W. Young, 50, far left—a veteran of four spaceflights during the Apollo program—and pilot Robert L. Crippen, 43, will be aboard for the first flight. Their job is not without peril. Consequently the jetliner-like flight deck will carry ejection seats.*

Beneath the flight deck lie cramped living quarters, which will include three bunks, one toilet, an oven, and storage for 74 different types of food.

Feigning zero gravity, *scientist astronauts clamber around the innards of a spacelab mock-up at Marshall Space Flight Center, Huntsville, Alabama. From left foreground are Europeans Ulf Merbold, Claude Nicollier, and Wubbo Ockels. Americans Michael Lampton and Byron Lichtenberg are at rear. One European and one American will staff the initial spacelab mission.*

For the first time, astronaut ranks include women. A total of eight are training at Houston.

KERBY SMITH

tough reflective sealer, cover the underside and those other parts of the orbiter that will be subjected to severe reentry heating. They look like the pieces of a great black jigsaw puzzle (pages 324-5).

Designing and putting that jigsaw puzzle together has been painstaking. The tiles have varying shapes and thicknesses. Many of them have to curve with the contours of the orbiter. A computer tailors and cuts each tile, which is then attached to the orbiter by hand, using a space-age glue that everyone publicly expects—and privately prays—will hold through the rigors of flight. If just one tile from a critical part of the orbiter falls off, the entire spacecraft could be severely damaged.

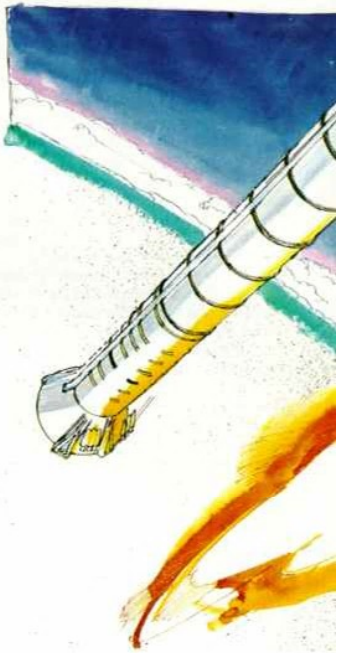
Rocket Engines: Nozzles and Pipes

The greatest challenge to the shuttle designers, however, has been the three big main engines on the orbiter. At full power these engines release as much energy as 23 Hoover Dams. Yet the engines weigh only 7,000 pounds each and, minus their nozzles, stand only five feet tall.

I am not sure what I expected to see at a factory that makes rocket-ship engines. Maybe lots of chrome and glitter. Certainly sparkling-clean assembly rooms. But a day at Rockwell's Rocketdyne plant in Los Angeles showed me that rocket making is a heavy, sometimes grimy, industry. It involves casting and welding thick chunks of metal, firing them in room-size furnaces, and dipping some of their components in great vats of electroplating chemicals. Under construction, these engines looked to me like glorified car motors with nozzles. Except for the intricate plumbing.

More than a thousand tiny tubes, for instance, run up and down the sides of the nozzles. During combustion these tubes siphon off the engine's frigid hydrogen fuel and use it to cool the nozzle enough to keep it from melting. More tubes then collect the hydrogen and feed it back to power two turbines that jump the pressures within the engine to nearly 700 times that of a typical household pressure cooker.

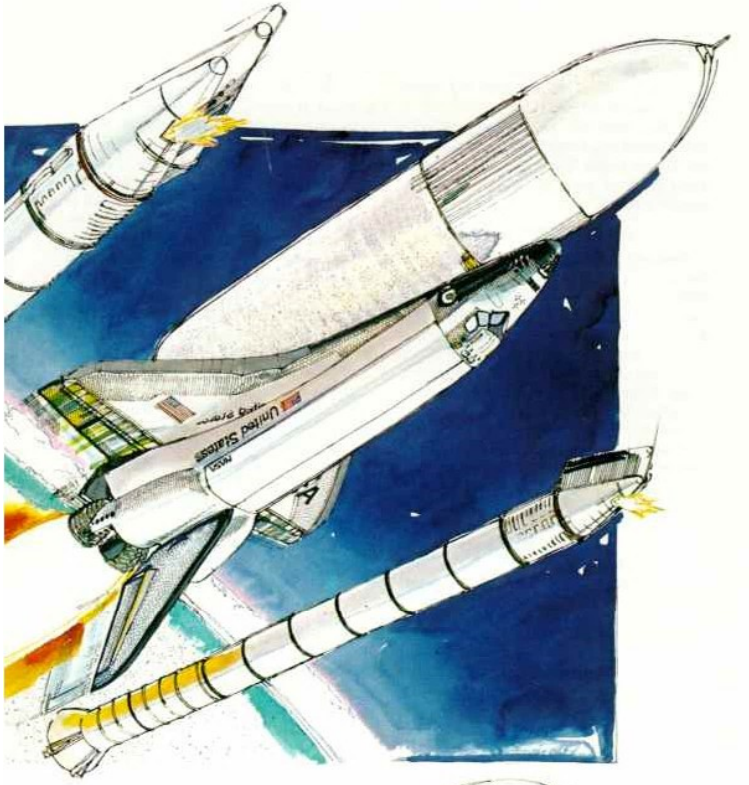
The engines need to burn hydrogen under those high pressures to get maximum thrust. Such pressures put unprecedented demands on rocket-engine technology. In test firings,

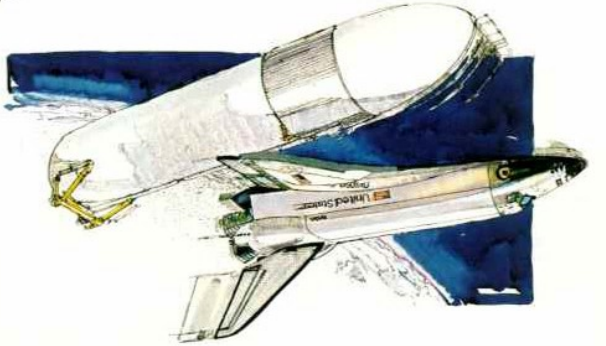


Rocketing into orbit

LAUNCH PLUS two minutes: Fuel spent, the solid-rocket boosters are jettisoned 31 miles up ***(above)****. Explosive bolts pop the rockets free; small rocket motors then propel them outward.*

About six minutes later at an altitude of 59 miles, the main engines are shut down and the external tank is jettisoned ***(right)****. Inverted flight facilitates separation. Smaller engines fire to maneuver "Columbia" into orbit.*





turbine blades have fluttered and cracked, bearings and rotating parts have broken down. Sometimes combustion has begun where nobody wanted it.

It has taken the Rocketdyne engineers about a year longer than anticipated to work out the problems. For a while the main engines received most of the blame for the shuttle's delays.

A Problem With Tiles

Then the thermal tiles proved much trickier to apply than expected. The *Columbia* had to be ferried from California atop a 747 with only a small number of its tiles in place. Enroute fake tiles, put on to protect parts of the craft from aerodynamic damage on the flight, fell off, ruining some of the real tiles. Later, thousands of tiles had to be removed and rebonded, giving the whole tile program an aura of fiasco. There were also delays in developing the computer programs that are used in the flight simulators that astronauts train in. That meant that even the astronauts could not have been ready on time.

One component that could have made the original date, however, is the huge external tank. "It's an 80,000-pound balloon," says one NASA engineer. "It's a big tin can," says another. Some tin can. The external tank is actually the backbone of the whole shuttle system. Both the solid rockets and the orbiter are bolted to it, and the overwhelming thrust these five engines produce at launch converges on the struts and beams of the external tank.

"In one spot the tank's shell may have to be membrane light and right next to it be able to withstand the equivalent of an enormous explosion," said Joseph Marcus of Martin Marietta, which runs NASA's Michoud assembly plant near New Orleans. "The tank also has to hold twenty times its weight in propellant, and keep it at hundreds of degrees below zero."

It takes more than half a mile of welds to put an external tank together. Once assembled, a tank is sprayed with foam insulation. Why insulate the tank? For one thing, the shuttle's odd shape will cause drag during its ascent, and parts of the tank will get quite hot. Since aluminum loses strength above 350°F, an unprotected tank might fall apart before it separates from the orbiter.

After separation the tank will reenter the atmosphere and disintegrate. Recovering it is not now economical, but eventually a small thruster, which would take the tank on into orbit, could be added. Bright aerospace-industry minds are dreaming up ways to use the discarded tanks. Perhaps several could be the core for a space station. Maybe the aluminum could be recovered to build ferries going from the shuttle's low earth orbit to construction sites higher up.

What happens for the time being when the external tank breaks up? The question is timely in light of NASA's problems with the falling debris from the dying Skylab.

"We target where the tank will land," says Porter Bridwell, one of NASA's external-tank program managers. "We have selected a site over the Indian Ocean at least 200 miles from land and with low density shipping. We have enough insulation to keep it intact down to 165,000 feet. The debris footprint will be 100 miles wide and 600 miles long."

How big will the pieces of this 80,000-pound balloon be?

"That's a good question," said Bridwell. "It's a magic art trying to predict that sort of thing. I just don't know."

Flight Transforms an Ugly Duckling

"I'm a test pilot, and this is the ultimate in test flying," Vance Brand, one of the eight astronauts being trained to fly the shuttle, said in his office at the Johnson Space Center. "I'm really excited about this vehicle. On the ground it may be stubby and look like an ugly duckling, but when it gets into the air, it's beautiful. It's a true air machine."

What will it be like to be in the cockpit of this ultimate flying machine? Brand and his seven colleagues helped me imagine being on space shuttle flight one.

The feisty solid rockets make launch seem more like a lunge toward space. The astronauts are pressed hard against their seats, amid more roar and shaking than on any previous manned flight. Two rocky minutes after lift-off there is a bang and a lurch when explosive bolts blow the spent solid rockets away. Speed builds as fuel in the external tank is consumed and the shuttle lightens. Soon the computer pilots have to throttle back the engines to keep the orbiter from

An engine's growing pains

*HIGH-PERFORMANCE blend of complexity and sophistication, an orbiter's main engine (**center**) is rigged for a test firing at the National Space Technology Laboratories, Bay St. Louis, Mississippi. It is the most efficient rocket engine ever built.*

The development of such power put currently available materials to the test, and engine failures have played a significant role in the delay of the shuttle program.

*In Los Angeles a Rocketdyne engineer inspects tube alignment in the engine's main injector (**top**). Other engineers check impellers and rotors of a high-pressure fuel turbopump (**bottom**), whose shaft rotates at 35,000 rpm—twice that of a shaft in a conventional jet engine.*

exceeding the speeds its winged structure can withstand.

The astronauts are flying upside down now, riding the underside of the external tank. This will help the orbiter separate from the more massive tank with a minimum of thrust and of G-force discomfort. It also gives a stunning view of the blue, cloud-speckled earth. The sky has turned black. But there is little time to sightsee. All eyes must concentrate on the TV monitors that detail the health of the mission.

Suddenly the main engines shut off. Sixteen seconds later more explosives signal that the external tank has been separated. Excess fuel streams from the tank, and it spirals off. Now for a minute and three-quarters, while the tank moves safely away, the orbiter drifts. Astronaut Bob Crippen checks position, trajectory, and systems data to make sure the orbiter will indeed be able to reach orbit. (Otherwise, the crew could abort and fly once around the world and home onto a desert landing site in New Mexico.) Comdr. John Young then gives the autopilot the go-ahead. The OMS engines flare to life. One OMS burn takes the machine on up to orbital height. A second burn 35 minutes later makes its orbit circular.

Power to burn

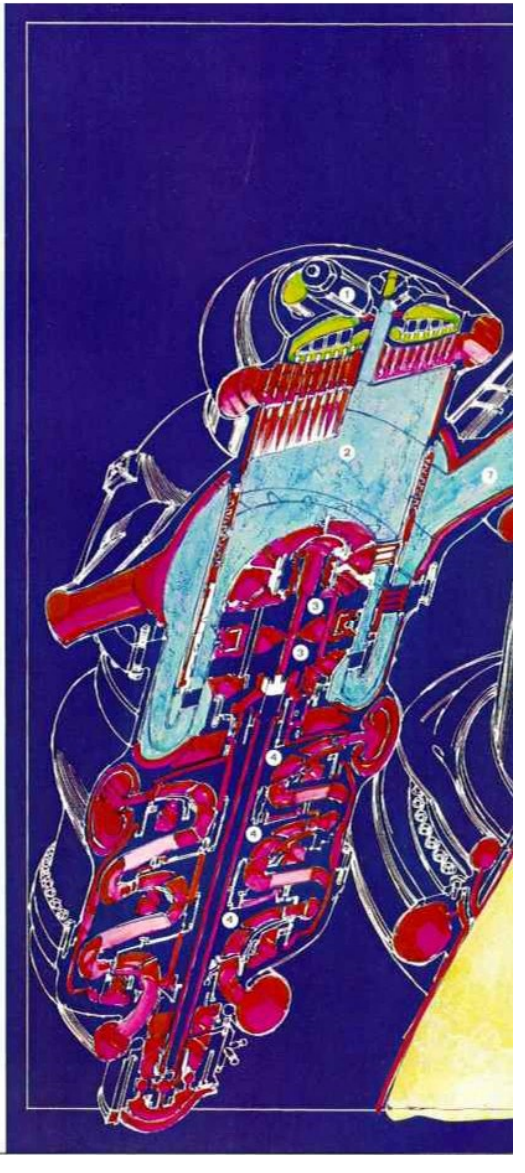
THUNDERING at launch for eight minutes, an orbiter's main engines generate more than enough power to light the state of New York. Their 12 fuel and oxygen turbopumps produce more than the horsepower needed to propel a battleship, with enough left over to drive seven nuclear submarines.

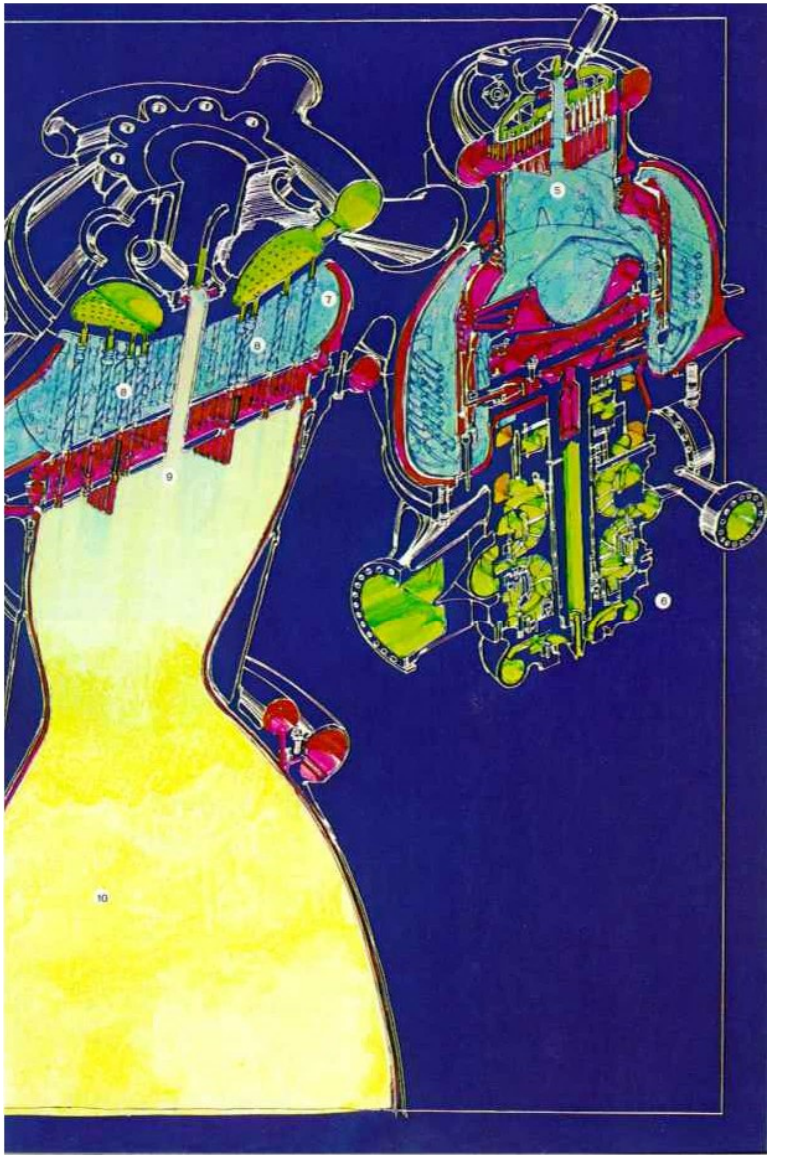
*A main engine (**right**) consists of a central rocket engine flanked by two smaller combustors that drive the turbopumps.*

*A spark igniter (**1**) flames a hydrogen-oxygen mixture in one combustor (**2**) to drive the turbines (**3**) and impellers (**4**) of the high-pressure hydrogen turbopump. Small as an oil drum but generating the power of 28 diesel locomotives, this pump compresses the hydrogen fuel to a pressure of 6,000 pounds per square inch.*

*Meanwhile, another combustor (**5**) powers the high-pressure oxygen turbopump (**6**). Exhaust gases from the combustors pass through manifolds (**7**) into the main injector (**8**), where tubes deliver the hot hydrogen gas and liquid oxygen to the main combustion chamber (**9**). Its temperature of 5500°F far exceeds the melting point of steel.*

*Liquid hydrogen at minus 423°F circulates in passages that surround the combustion chamber and main engine nozzle (**10**) to maintain metal temperature at a relatively cool 1000°F.*





World's strongest parachutes

*HEAVIEST PARACHUTE PAYLOADS—80-ton solid-rocket boosters—return to earth for recovery and reuse, each borne by three enormous chutes (**left**) whose combined diameters exceed the length of a football field. Deployed at 6,600 feet with the rockets traveling at 225 miles an hour, the nylon chutes have many gaps (**above**) to cushion the shock of opening. After splashdown in the Atlantic Ocean, the rockets will float like buoys.*

The main purpose of space shuttle flight one is to test out the spacecraft. So most of the next 55 hours in space will be spent making sure all systems are working. Almost immediately the crew will open the big silver doors of the cargo bay. "We keep the doors open for most of the flight," says Crippen. "Radiators inside the doors throw into space the considerable heat that builds up from all the electronics on board."

Later a critical test will be closing the doors again—a must if the crew wants to come home in one piece. The doors could warp from uneven solar heating. Their motors or the latches could fail. If difficulty arises, Crippen may have to don a space suit, go outside, and fix the problem.

On the second day in space the crew will rehearse their deorbit routine. Then they do it for real. Small reaction-control jets turn the orbiter around, engines first. Over the Indian Ocean, the OMS engines burn for two minutes to slow the orbiter slightly from its orbital speed, equivalent to about 25 times the speed of sound. The craft begins to drop and is turned nose up so that its tile-coated belly will absorb the reentry heat when it hits the atmosphere some 35 minutes later over Midway Island. By now the orbiter is banking and flying wide traverses to control its speed. The strain on the structure is tremendous, and NASA has only wind-tunnel data to say that the machine will not fall apart. Nevertheless, vouches astronaut Joe Engle, "We're going to be concentrating so hard there won't be time to be nervous."

Gradually the nose begins to drop. By the time it becomes visible from earth, the orbiter is diving ten times more steeply than a jetliner on its landing approach, and Commander Young is flying it manually. (The autopilot could let Young land with his hands folded, but NASA figures that a manned landing is safest for the first flight.) At about 1,800 feet over the Mojave Desert and a speed of 290 knots, Young lifts the nose and gently pulls out of the dive. At 270 knots he lowers the landing gear, and at 190 knots he touches down, puts on the brakes, and bounces to a stop on the wide-open dry lake bed at Edwards Air Force Base.

Four months later, *Columbia* will fly again. After four test flights, landing will be on the much narrower runway at Canaveral. The shuttle will be declared operational.

The bulk of the shuttle's work will have little to do with flying. So a person doesn't have to be a pilot to be an astronaut. Actually, in the future, "the best man for the job may be a woman." That's what the sign over Dr. Anna Fisher's desk in Houston reads. None of Dr. Fisher's new astronaut colleagues would bother to disagree. Initially, there was a lot of media attention, and some new space clothing had to be designed. Otherwise, neither Dr. Fisher, fellow physician Rhea Seddon, biochemist Shannon Lucid, electrical engineer Judith Resnik, physicist Sally Ride, geologist Kathryn Sullivan nor five more recently appointed women astronaut candidates have disrupted the previously masculine normalcy of Building Four, the astronaut headquarters at the Johnson Space Center.

Since 1978, 35 people have been added to the astronaut roster; 19 more are in training. These are divided into two groups: shuttle pilots and mission specialists—the people who will run the experiments and carry out the business of each shuttle flight.

When I visited Houston, the first 35 were in the middle of an intensive training program to gain background in fields as diverse as oceanography and solar physics. "It's been like taking a drink from a fire hose," said pilot Dan Brandenstein. "Like trying to absorb three years' worth of orbital mechanics in three hours." "It's an incredible experience," said Dr. George Nelson, a 30-year-old astronomer. "It's living out your fantasies."

Escape Hatches Are Portable

One of the early screening tests for the hundreds of astronaut applicants was a 15-minute stint in an inflatable canvas contraption called a "rescue ball." This tested for claustrophobia. If the shuttle has a problem in orbit that would keep it from coming home, each specialist could crawl into one of these balls. I tried it. It's like entering a collapsed pup tent. You sit cross-legged, zip yourself in, and inflate the ball. (Pilots have extravehicular space suits to escape in.)

Rescuers from a second shuttle would rendezvous with the disabled spacecraft, crawl through the hatch, pull the crew members out in their cocoons, and string each ball to a

tether. The pressurized balls have enough oxygen to keep their guests alive for three hours. But what if rescuers flubbed, or the ball came untethered? It would be quite a view through the peephole, as one drifted off to become a human satellite in a pod.

Bob Everline, one of the men in Houston who decide how to utilize the shuttle, says the first 40-some flights are sold out. "Through 1986 there's very little space left."

The first shuttle payload will be a series of environmental and earth-resources experiments on flight two. One experiment will evaluate whether orbiting radar can be used to make geological maps good enough for oil and mineral exploration. Another will measure ocean color, as a means of locating plankton or good fishing grounds. Other equipment will measure man-made carbon monoxide pollution in the atmosphere and study the structure of lightning from above.

Although flight four will carry up either a science pallet or a military satellite, the main business of the first four flights will be checking out the spacecraft.

Most of the satellites the shuttle carries up will be deployed with a spring, or if they must go to higher orbits, with secondary rockets called upper stages. A few satellites will simply be picked up and dropped overboard by the remote manipulator system (RMS), that skinny 50-foot-long arm with a clever claw. However, the arm's most important chore will be retrieving payloads from space. The shuttle will pull up within 35 feet of an object, the claw will grab it, and the arm will haul it in.

"Learning to use the RMS could be a career in itself," says astronaut Gordon Fullerton. "It's got a bunch of joints—shoulder, elbow, wrist, and grabber. All have to be coordinated. You operate it with two hand controls. It takes a lot of practice. You could bash a hole in your spacecraft with it, so you don't flail it around indiscriminately."

The arm will be tested on flight two, and one of its early assignments will come in October 1984, when it deploys—and about a year later retrieves—LDEF, the long-duration exposure facility. LDEF is a big, free-flying space ark with a menagerie of experiments and materials that scientists want to expose for long periods to the uncertainties of space. These materials range from novel composites that could be used in space construction in the 1990s, if they prove space-hardy, to substances that catch cosmic-ray particles and micrometeorites or that absorb interstellar gases.

LDEF experimenters will also send up spores and seeds, bring them back, and grow them to see, for one thing, whether future space agriculture might encounter unusual rates of mutation.

On the mission that carries up LDEF, the shuttle will also retrieve the solar maximum mission, a satellite that has been focusing telescopes and other instruments on the sun's surface during a period of maximum sunspot activity. This orbiting observatory will be the first to monitor solar flares outside the blurring, obscuring atmosphere.

A Chance to See Farther Into Space

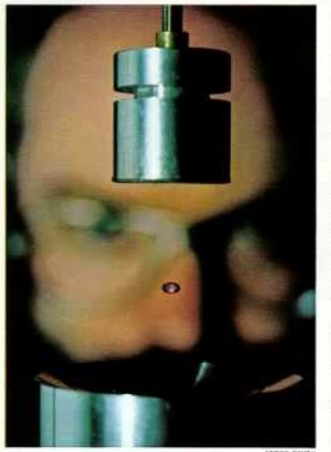
The atmosphere, which dims incoming light and makes the stars twinkle, has long frustrated astronomers. They are overjoyed with the new vision the space shuttle promises. In 1985 the shuttle will deploy the 45-foot-long space telescope, which will train five astronomical instruments on tantalizing regions of the universe. The space telescope will detect objects 50 times fainter than those seen by the best earthbound instruments. We will be able to see seven times deeper into space, and look at up to 350 times the volume of universe now visible.

Our knowledge of the universe should take off like a solid rocket as we zoom in on mysterious objects such as quasars and pulsars and locate black holes and perhaps the borders of the universe itself.

The shuttle will also take up infrared-measuring instruments that will study dense dust regions 17 trillion miles and farther away, where new suns may be forming. X-ray emissions from white dwarfs, black holes, and other collapsed stars across the universe will be detected much more easily. In one year of observation, astronomers expect to discover more than a million new sources of intense X-ray emissions.

The cream of the shuttle's scientific payloads, however, is called spacelab, which, when it flies, basically turns the cavernous payload bay of the orbiter into an all-purpose laboratory. Spacelab features a 23-foot-long habitable module, where people

can work in shirt sleeves. Spacelab also has five ten-foot-long pallets, which attach outside the module and carry experiments that can or should be exposed to open space. The module and all five pallets cannot fit all together in the orbiter bay, but spacelab is flexible. Depending on the mission, NASA can break the module in two and fly half of it with varying numbers of pallets. Spacelab will stay in the orbiter bay throughout its



KENDY SMITH

Defying gravity's tug, *high-intensity sound waves suspend a water droplet to simulate the reduced gravity of space. The technique could be used to confine molten materials for processing aloft without contamination—a sort of furnace without walls.*

mission, which will typically be seven days.

Spacelab brings the first European accents to the U. S. manned space program. It was built by a consortium of companies in member countries of the fledgling European Space Agency. Moreover, a German, a Dutch, and a Swiss scientist are being trained as astronauts.

"Spacelab is very well known now in Germany, very popular," said a spokesman for ERNO, a West German firm that assembled the system. "We in Europe are convinced that space is going to be a good business."

Many of spacelab's experiments will focus on understanding earth's atmosphere and remote-sensing its environment. But the Germans are most intrigued by the prospect of using the nearly zero gravity of space to manufacture materials that cannot be made on earth. These include purer crystals for electronics components—and hence faster, smaller computers—along with better drugs and unheard-of alloys of metals that simply will not mix on earth. And so, among its trove of laboratory equipment, spacelab will have many furnaces for materials processing and incubators for biological experiments.

Rivals for the Northern Lights

There is disagreement and often pessimism in this country about the prospects for industrializing space, but the attitude I picked up in Europe was that zero gravity is such an unusual environment that it would be highly abnormal if the unexpected—and potentially very profitable—did not occur there.

Spacelab's most spectacular piece of equipment is being developed in Japan, another country that is eager to glean some of NASA's space know-how.

"We are going to send up a very big electron accelerator," explained Professor Tatsuzo Obayashi in Tokyo. "In one experiment we will eject some plasma gas into space and shoot a beam of electrons into it. We hope to produce artificial auroras borealis—perhaps over Tokyo or Washington."

A careful eye would be able to detect these auroras, which would be several miles long and sixty miles high. Spacelab sensors will see them in detail. The data they record will help verify our theories about how discharges of electrons from the magnetosphere cause natural auroras. Other spacelab accelerator experiments are basic physics: How do charged gases called plasmas and electron streams interact? The sun is a giant electron source, and the upper atmosphere is rich in plasmas. Spacelab experiments could help us understand how the sun's cycles affect our long-term climate.

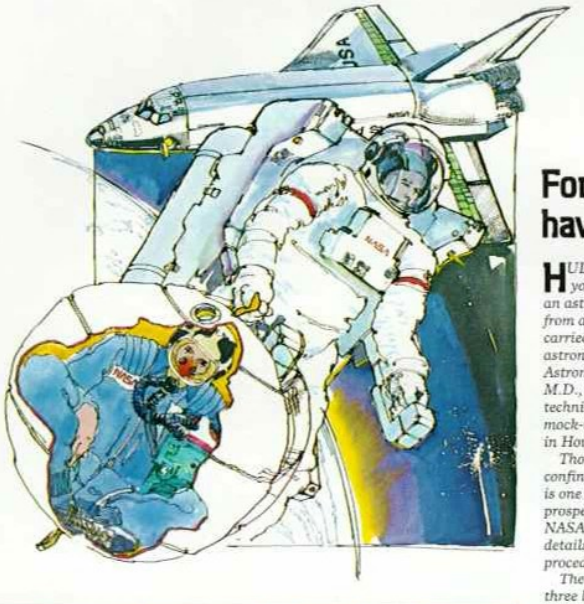
Spacelab does have its drawbacks. A single spacelab flight costs 26 million dollars.

A superscope to eye the cosmos

*HIGH-FLYING maintenance man, an astronaut tethered to an orbiter climbs aboard a space telescope (**below**). The event, photographed in miniature at a California movie studio, is not likely to happen before 1986. But space-suited orbiter crew members at NASA's Huntsville facility practice the task underwater (**right**), to experience the weightlessness of space.*

Above the turbulence and haze that hamper terrestrial telescopes, the telescope—most powerful ever built for use in space—will increase man's view of the cosmos 350-fold, perhaps to the fringe of the visible universe to reveal the birth pangs of the first galaxies.

KERBY SMITH AND BRICK PRICE (ABOVE); KERBY SMITH (RIGHT)



RHEA SEDDON, M.D.

For rescue, have a ball

*HUDDLED like a yogi in a protective ball, an astronaut is rescued (**left**) from a disabled orbiter and carried by a space-suited astronaut to a sister ship. Astronaut Rhea Seddon, M.D., demonstrates the technique (**bottom**) in a mock-up of the "rescue ball" in Houston.*

Though a 15-minute confinement in the ball is one of the tests for prospective astronauts, NASA is still refining details of construction and procedure.

The ball will likely have three layers. From inside out: leakproof urethane-coated nylon, expansion-resistant polyester, and an insulating material to cope with temperatures from minus 160° to plus 250°F.

The rescuer wears a spacesuit and backpacks designed for extravehicular activity, including maneuvering in space. His left hand controls jets of compressed nitrogen at the corners of the backpack for propulsion.

And so, for those who cannot afford this price tag, NASA administrator John Yardley came up with a low-cost alternative—the getaway special.

A getaway special is simply a canister, which can range from two and a half to ten cubic feet, and which NASA will fly standby when it has space available. Whatever is in the canister must take care of itself, with its own microprocessors, batteries, and controls. The shuttle crew will only flip a switch to turn the experiments on or off.

The getaway special is the obsession and almost a second career for an irrepressible Ogden, Utah, engineer named Gil Moore. Moore practically bounds around the country promoting the specials, pursuing civic groups, school boards, businesses—anyone who can raise the $3,000 to $10,000 getaway fare in order to give some kids in their town the chance to put an idea into space. So far more than 300 specials have been reserved.

From Solar Sails to Weightless Farms

Moore introduced me to dozens of students in northern Utah working on getaway projects. I heard a deluge of ideas. University of Utah students are planning to send up a solar sail, a membrane that would catch photons from the sun as a means of propelling a spacecraft. They were displeased that NASA had abandoned solar-sail research and want to demonstrate its feasibility.

Others want to determine whether spores or primitive bacteria can withstand cosmic rays. If so, perhaps life on earth could have been seeded from elsewhere. One high-school student has decided to try to make a light foam form of metals that might be used in space construction. Another simply wants to melt solders and see how they re-form in zero gravity. Several young biologists plan to see how duckweed and chlorella, rapidly reproducing primitive plants that have been discussed as future space foods, grow without gravity.

"I wouldn't be at all surprised if some of these kids came up with some important results," said Utah State professor Rex Megill. "They don't have the constraints of conventionality or peer review."

President Anwar Sadat has reserved four getaway specials for Egyptian students. The Japanese newspaper *Asahi Shimbun* ran a contest to solicit ideas for its special. In six weeks it received 17,000 suggestions.

Many businesses, too, look at the canisters as a cheap and secretive way to test out space-manufacturing concepts.

NASA, however, does have two regular first-class passengers. One is the communications industry. Even at 40 million dollars a launch, the space agency can hardly send satellites up fast enough to meet the booming worldwide telecommunications demand. The space shuttle should be able to put four satellites in orbit for the current price of one.

Building a New World in Earth Orbit

Not too far down the road are huge telecommunications platforms that would actually be constructed in space. These platforms would be able to carry 250,000 simultaneous telephone calls. On earth special receivers will let viewers tune in almost any TV station in the world. Platforms may make video phone calls commonplace.

Communications revenues from these platforms could run 40 to 80 billion dollars annually by the year 2010. Plans for building the huge structures are well under way.

At Rockwell International I saw ball-and-socket joints that will let remote manipulator arms snap the struts of a space structure together like poppet beads. General Dynamics engineers showed me an antenna that astronauts could unfurl in space as if they were springing open an automatic umbrella. McDonnell Douglas would like to have the platforms assembled by workers in shuttle-borne cherry pickers.

General Dynamics and Grumman are testing prototype machines that extrude triangular beams that can be space-welded into massive shapes. "I can produce a single beam 14 miles long if I want," said General Dynamics' Jack Hurt. These aluminum or composite beams are so light I could crinkle them in my hand. Yet in space they could support the weight of an aircraft carrier.

The Air Force is NASA's other regular customer. A separate shuttle launch facility is being constructed at Vandenberg Air Force Base in California, and a top-security flight-control center for exclusive military use has already been set up in Houston.

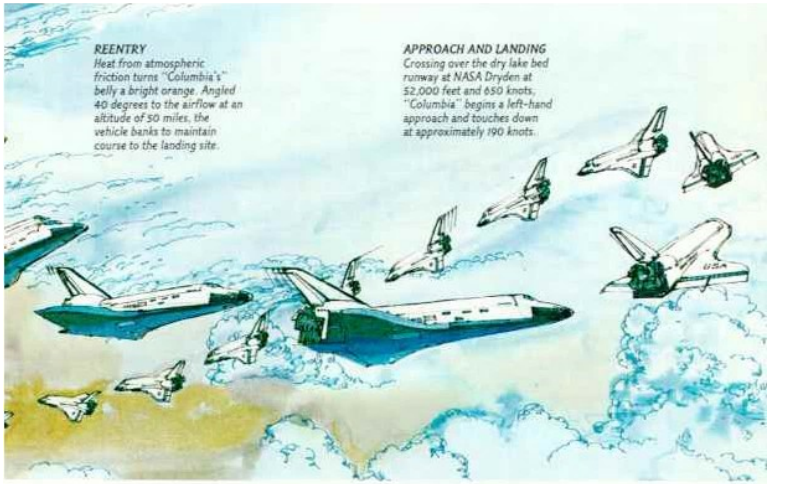
The military is the main driver right now

DE-ORBIT BURN
As "Columbia" travels backward and upside down at 15,200 knots, pilots fire the maneuvering engines to nudge the craft from a 150-mile-high orbit. Thrusters jockey the vehicle to a nose-high attitude for entry.

NASA (BOTH)

With a svelte tail cone mounted to reduce aerodynamic drag, a test orbiter banks (**above**) during initial landing trials in late 1977 at NASA's Dryden Flight Research Center in California. Later the cone was removed to expose the engines to simulate an approach after reentry from space (**right**). Here drag takes effect, and the orbiter descends at around 15,000 feet a minute—20 times faster than a jetliner. The rudder splits open to serve as a speed brake.

Flight computers will control "Columbia" from reentry to the approach, when the crew will take over for a manual landing. Though automatic landings may later become routine, the crew will still have to lower the landing gear and man the brakes.



for advanced—and mostly top-secret—space programs. They will put into geosynchronous, or stationary, orbit 23,000 miles high, extremely sophisticated surveillance satellites, including antennas up to a thousand feet in diameter. They would also like to begin doing assembly work in low earth orbit by 1985—on what we do not know. By the early 1990s they will probably need a transfer vehicle to take men from the shuttle's orbit to the ultrahigh geosynchronous levels to assemble or service their equipment.

The Russians reportedly are also building a shuttle-type vehicle, one smaller than ours. They are establishing permanent space stations, and have been working on killer satellites that could destroy enemy spacecraft. With so much of the world's military and commercial communications going into orbit, space is a logical war front in the future.

Some Earthbound Hazards

Many shuttle advocates are worried that the system will be overly dominated by the military. However, there are other clouds in the space shuttle's future. One is pollution. At 50 flights a year, emissions from the solid rockets could decrease the ozone layer by as much as .25 percent, letting slightly more ultraviolet radiation reach earth. NASA claims the effects will be insignificant, and that later versions of the space shuttle in the 1990s may well be pollution free.

Between the telecommunications industry and the military, NASA now foresees no trouble keeping all four orbiters, and a fifth one it hopes to build, busy indefinitely. In fact, it will most likely turn the management of the shuttle over to private industry in a few years.

The space program, however, is more than communications and military satellites. NASA's science payloads are just not getting much money any more. That means spacelab's future is unclear. Sadly, there are few new planetary missions planned. The agency does not even have the funds to fly a once-in-our-lifetime rendezvous with Halley's Comet in 1986.

Just where we are going in space and how fast will depend on NASA's budget. That depends in turn on politics and the national will. Perhaps if the Soviet Union does, indeed, develop a killer satellite, it will spur us more rapidly into space, just as Sputnik did two decades ago. The odds are that the shuttle era will evolve more gradually and that as profitable uses are demonstrated private enterprise will come in with capital.

In ten years the current shuttle surely will seem outdated. In 50 years we will probably look back on it as we do the covered wagons that took us to our first frontier. To me the real importance of the shuttle is that it is maintaining a frontier for us. This country cannot grow without one. □

Flanked by two chase planes, the test orbiter "Enterprise" lands in a cloud

of dust on the dry lake bed at NASA's Dryden Center.